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Launch Vehicle Communications

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This report is a formal draft or working paper, intended to solicit comments and ideas from a technical peer group.

This report contains preliminary findings, subject to revision as analysis proceeds.

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Launch Vehicle Communications

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Abstract

As the National Aeronautics and Space Administration's (NASA) planning for updated launch vehicle operations progresses, there is a need to consider improved methods. This study considers the use of phased array antennas mounted on launch vehicles and transmitting data to either NASA's Tracking and Data Relay Satellite System (TDRSS) satellites or to the commercial Iridium, Intelsat, or Inmarsat communications satellites. Different data rate requirements are analyzed to determine size and weight of resulting antennas.

Introduction

Launch vehicle (LV) operations are always in need of enhanced communications capability to keep pace with growing requirements. To support operations at more than one launch pad at a time and to improve safety, there is a growing need for larger amounts of data, including video, to pass between the LV/payload and launch control.

Currently, communication needs are met by various types of dish antennas. By their nature, dish antennas are limited to one-on-one links and require mechanical slewing to maintain pointing. To support multiple operations and to seamlessly switch from one launch pad or launch vehicle to another–even launch pads at large geographical separations–and to readily track launch vehicles as they ascend into orbit, mechanically driven dishes present a limiting situation. The limitations are in both covering launch pads that are beyond line of sight and serving multiple links.

A possible mitigation of these limitations could be met by employing phased array antennas transmitting through communications satellites. This paper assesses whether commercial or government communications satellite systems could provide launch vehicles with Megabit per second (Mbps) data rate capabilities using phased array antennas. The considered data rates in this paper were 1, 5, and 10 Mbps. For the purposes of this study, the satellite systems can be in Low Earth Orbit (LEO), Medium Earth Orbit (MEO), or Geosynchronous Earth Orbit (GEO), and can operate in L, S, Ku, or Ka-bands.

It is noted that this study merely attempts a high-level assessment and certain specific considerations need to be explored more fully before an actual decision of usage can be made.

Satellite Systems and Study Assumptions

The communications satellite systems used in this study are three commercial and one government systems. The commercial systems are the LEO Iridium© [1] and the GEO Inmarsat© [2] and Intelsat© [3]. The government system is the GEO Tracking and Data Relay Satellite System (TDRSS) [4].

Satellite system parameters used in this study are the frequency band and satellite Gain/Temperature Ratio (G/T). The parameters used are shown below in table 1.

TABLE 1.—FREQUENCY AND G/T PARAMETERS

Satellite	Frequency (GHz)	G/T (dB/K)
Iridium	1.623	-16.315
Inmarsat	1.635	-11.5
Intelsat	14.25	9.0
TDRS-S	2.25	9.50
TDRS-Ku	15.003	24.40
TDRS-Ka	27.50	26.50

To conduct this study, certain values for basic antenna parameters needed to be assumed. Below is the list of assumptions.

- 3 dB link margin
- 1e-9 Bit Error Rate
- 3 dB of additional losses
- Radiating element spacing of $0.75 * \lambda$
- 20 lbs. per square foot of array
- QPSK modulation
- No error coding
- 60° scan angle allowed (-4.5 dB Scan Loss)
- Patch radiating elements with 3 dB Gain
- Element DC power of 200 mW
- SPA efficiency of 20 percent
- Power supply efficiency of 80 percent

Study Results

Based on the assumptions listed above, this study calculated the number of elements required to close the link, the length of a square array that results from that minimum number of elements, and the resulting weight for the array. Table 2 shows the resulting sizes of arrays that would be required to support data rates of 1, 5, or 10 Mbps for the various communications satellite systems.

TABLE 2.—LENGTH AND WEIGHT COMPARISONS – SINGLE PHASED ARRAY ANTENNA

Satellite System (Frequency Band)	1 Mbps		5 Mbps		10 Mbps	
	L (in)	W (lb)	L (in)	W (lb)	L (in)	W (lb)
Iridium (L)	52.66	386.08	79.90	888.77	96.24	1289.54
Inmarsat (L)	166.03	3828.79	241.83	8122.61	290.56	11725.67
Intelsat (Ku)	17.19	41.02	25.26	88.64	30.23	126.94
TDRS (S)	41.97	244.60	61.64	527.66	73.44	749.09
TDRS (Ku)	6.88	6.58	10.42	15.09	12.19	20.65
TDRS (Ka)	4.40	2.69	6.65	6.15	7.94	8.76

This study also looked at three possible launch vehicles, namely Delta [5], Atlas [6], and Titan [7]. Based on LV diameter and the determined length of the arrays, a quick analysis was performed to decide whether the launch vehicle’s dimension could support three arrays. Given a limitation of a 60° array scanning angle, three arrays are required to obtain full 360° coverage. The assumption was that all three arrays would lie along only one circle. Table 3 below, ascertains whether three phased arrays could possibly fit on the given LV (YES or NO decision), and what the combined weight of the three arrays would be, for the three data rates and for the six communications satellites cases.

TABLE 3.—LAUNCH VEHICLE ARRAY ACCOMMODATION (YES/NO)/TOTAL WEIGHT (LBS)

Satellite	Rocket	1 Mbps	5 Mbps	10 Mbps	1 Mbps	5 Mbps	10 Mbps
Iridium	Delta	YES	YES	YES	1158.25	2666.31	3868.63
	Atlas	YES	YES	YES	1158.25	2666.31	3868.63
	Titan	YES	YES	YES	1158.25	2666.31	3868.63
Inmarsat	Delta	NO	NO	NO	--------	---------	----------
	Atlas	NO	NO	NO	--------	---------	----------
	Titan	NO	NO	NO	--------	---------	----------
Intelsat	Delta	YES	YES	YES	123.07	265.91	380.82
	Atlas	YES	YES	YES	123.07	265.91	380.82
	Titan	YES	YES	YES	123.07	265.91	380.82
TDRS-S	Delta	YES	YES	YES	733.80	1582.97	2247.26
	Atlas	YES	YES	YES	733.80	1582.97	2247.26
	Titan	YES	YES	YES	733.80	1582.97	2247.26
TDRS-Ku	Delta	YES	YES	YES	19.74	45.27	61.95
	Atlas	YES	YES	YES	19.74	45.27	61.95
	Titan	YES	YES	YES	19.74	45.27	61.95
TDRS-Ka	Delta	YES	YES	YES	8.06	18.44	26.27
	Atlas	YES	YES	YES	8.06	18.44	26.27
	Titan	YES	YES	YES	8.06	18.44	26.27

Conclusions

This study is a high level look at the possibility of using phased array antennas, transmitting through communications satellites, to provide higher data rate capabilities to support launch vehicle operations. Given this, specific decisions on whether a communications satellite system and launch vehicle combination makes sense will require more in-depth study. This study merely determines whether the notion of phased arrays, communications satellites systems, and various launch vehicles makes enough sense to warrant further study.

On the basis of this study, size and weight requirements for phased array antennas yield values that in some cases might be practical. This study shows that TDRS-Ka yields the minimum size and weight for the necessary phased arrays, but other communication satellite systems might be acceptable for certain launch vehicle operations. On the other hand, the resulting weights for Iridium and TDRS-S antennas preclude their practical use given the large weight penalty.

Another consideration is using less than three antennas. Scenarios that might allow this assume fixed launch azimuths and trajectory profiles that remain in view of the communication satellites. Specific cases require detailed analysis of the geometry of the trajectory profile with the communication satellites.

However, this paper limits itself to low weight results given the weight penalties associated with launch vehicle operations. Based on these results, there is reason to think that future higher data rate communications could be supplied via phased array antennas mounted on launch vehicles.

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[7] Spaceline, Inc., http://spaceline.org/rocketsum/titan-program.html, February, 2004.

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